1. Introduction

The force response of on elastic sphere impacting a rigid surface is governed by the impacting velocity, mass, radius of curvature, elastic modulus, and Poisson' ratio of the sphere. Researchers have found that the impact of a sphere on a fruit can be closely modeled by the impact of an elastic sphere and the firmness of a fruit has a direct effect on the impact force response[1].The small energy impact test was used to classifier fruits. A single lane madurity sorting systems was development wich used impact parameters (maximum force, maximum deformation, duration of impact ...)[2]. Under certain conditions, the impact test could be a non-destructive technique, using a 50 g sphere dropped from a 3 or 4 cm height on apple or pear and a determinated radius of curvature. The objective of this study is to determine experimentally the effect of the impacting radius of curvature on firmness sensing of fruits.

2. Experimental procedure

Two varieties of both pears ("Blanquilla" and "Decana del Congreso") and apples ("Golden Delicious" and "Starking") were tested. Fruits came from Lérida (Spain) and were transported to the Physical Properties Laboratory of the Agricultural Engineering Department in Madrid. All the fruits were stored in a 20±2°C room. Fruits were classified by weight, size, and freedom from mechanical injuries and decay.

A series of impact tests were performed to study the effect of the radius of curvature. A group of ten fruits was tested in a non-destructive impact. The impact test was performed using the impact test system developed by Chen et al. (1985)[3] (Figure 1). Two spherical tips with different radius of curvature (R_A = 2.48 cm and R_B = 0.98 cm; $R_A = 2.5\ R_B$) and equal mass were used (Figure 2). Four impacts to ten fruits of each variety were tested with both tips. Each fruit was impacted eight times, four with sphere R_A and four with R_B, alternately a long the perimeter. The fruit was dropped from a 4 cm height onto each pear; 3 cm in the case of apples. The acceleration of the rod during impact was measured from the data given by an accelerometer connected to the end of the indentor. The other impact parameters were calculated and recorded on a computer disk file.

During each impact, the spherical tip was first smeared with ink. When the tip came in contact with the fruit, it left an ink mark showing the area of contact. Each contact point was labelled, and the bruises in the fruit were allowed to develop for about 2 hours. The degree of bruise was evaluated by cutting through the center of the bruised region (perpendicular to the fruit surface) and measuring the maximum width and depth of the bruise with a stereo-microscope, (Nikon model SMZ-2T, x10-63), wich was equipped with a caliper and a camera. The fruit was ripened until there was bruise, and the different damage levels could be best observed.

3. Statistical analysis

The experimental design was a factorial design with a sample size of 10 units and four repetitions for each variety. An analysis of variance and of separation of the means (Student-Newman-Keul test) were carried out for nine impact parameters and width (W **(mm)**) and depth (D(**mm**)) of bruise. The chosen impact parameters were:

1.-Total duration **(ms)** . . . . TD
2.-Final duration at speed = 0 **(ms)** . . . . FD
3.-Time to maximum force **(ms)** . . . . TM
4.-Increment TD-FD **(ms)** . . . . IT
5.-Slope force/deformation **(N/m)** . . . . F/D
6.-Slope force/time **(N/s)** . . . . F/T
7.-Maximum force **(N)** . . . . MF
8.-Maximum deformation **(mm)** . . . . MD
9.-MF/F/T **(N^2 * 10^5/s)** C1

4. Results and discussion

In the four varieties studied, the size of bruise was smaller with a spherical tip A than with tip B (Table 1) (Figure 3 and 4). In this conditions, there were significant differences ($p < 0.05$) in both. Some time, the damage on "Blanquilla" with sphere A was a fissure to D mm of depth and W mm of width, but was not a bruise. The reduction of damage was more than 50% in all case.

VV.	BLANQUILLA		DECANA DEL C.		GOLDEN DELICIOUS		STARKING	
	A	B	A	B	A	B	A	B
MF	31.05^{A}	25.04^{B}	27.01^{A}	22.31^{A}	30.68^{A}	26.36^{A}	28.80^{A}	22.84^{B}
MD	1.40^{B}	1.67^{A}	1.43^{B}	1.74^{A}	1.08^{B}	1.29^{A}	1.11^{B}	1.28^{A}
F/T	21839^{A}	14740^{B}	21289^{A}	13368^{B}	23423^{A}	16665^{B}	23103^{A}	16239^{B}
F/D	28733^{A}	19169^{B}	26421^{A}	17184^{B}	35694^{A}	23688^{B}	33937^{A}	22851^{B}
CI	7.03^{A}	3.80^{B}	6.05^{A}	3.26^{B}	7.42^{A}	4.43^{B}	6.81^{A}	3.76^{B}
TD	5.39^{A}	6.40^{A}	5.49^{A}	6.50^{A}	4.39^{B}	5.63^{A}	4.63^{B}	5.55^{A}
TM	2.58^{B}	3.07^{A}	2.72^{B}	3.30^{A}	2.29^{B}	2.70^{A}	2.34^{B}	2.79^{A}
FD	1.98^{B}	2.31^{A}	2.37^{A}	2.37^{A}	1.86^{B}	2.29^{A}	1.80^{B}	2.05^{A}
IT	2.82^{A}	3.40^{A}	2.85^{A}	3.21^{A}	2.10^{B}	2.93^{A}	2.29^{B}	2.77^{A}
W	2.35^{B}	5.85^{A}	1.63^{B}	6.39^{A}	3.63^{B}	5.98^{A}	1.49^{B}	5.07^{A}
D	0.47^{B}	1.77^{A}	0.34^{B}	2.47^{A}	1.08^{B}	2.03^{A}	0.61^{B}	1.62^{A}

Table 1.-Results to the impact and damage parameters. If the superscript are diferent (A and B), there are significant differences. If the superscript are the same, there aren't significant differences.

5. Conclusion

The non-destructive impact test would cause less damage with a spherical impactor with a radius larger than 9.8 mm. A flat indenter must not to be used because the contact area would then depend to a greater extent upon the curvature of the fruit. This would increase the variability of the impact response.

6. References

[1]- CHEN, P., RUIZ ALTISENT, M. BARREIRO, P. (1993). "Effect of impacting mass on firmness sensing of fruits" ASAE paper nº 93-6542.

[2]-JARÉN, C. (1994). "Detección de la textura de frutos por medio de impactos no destructivos: desarrollo y aplicaciones del procedimiento de clasificación" Tesis Doctoral. Universidad Politécnica de Madrid.

[3]- CHEN, P., TANG, S., & CHEN, S. (1985). "Instrument for Testing the Response of Fruits to Impact." ASAE paper nº 85-3537.

Figure 1.-Impact testing system.

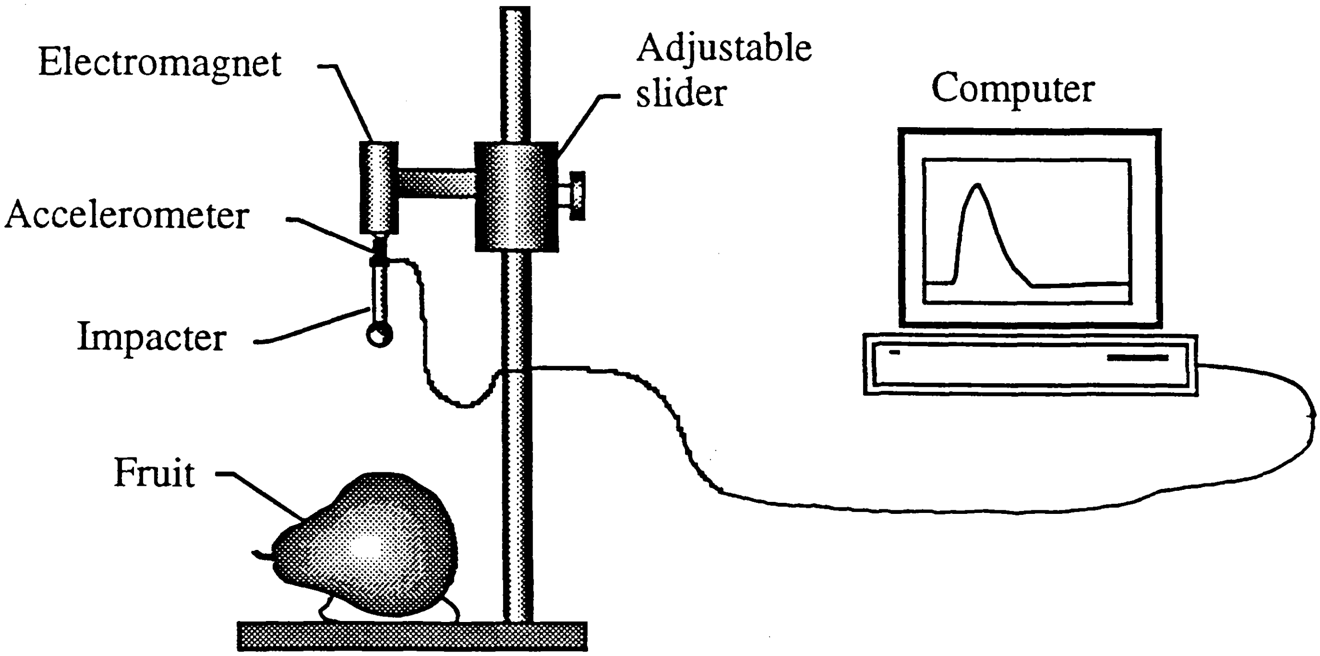

Figure 2.- The two spherical tip.

Figure 3.- Damage fruit with spherical tip A.

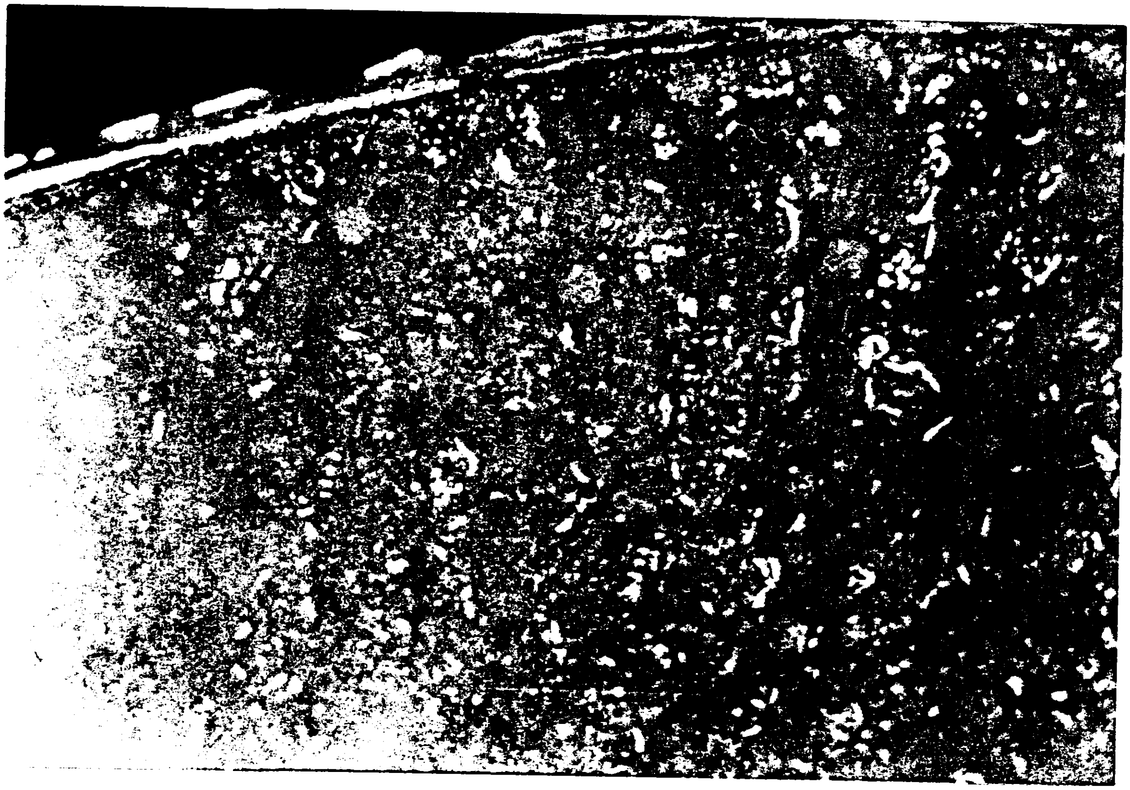

Figure 4.- Damage fruit with spherical tip B.